Evolvable Mars Campaign and Technology Development

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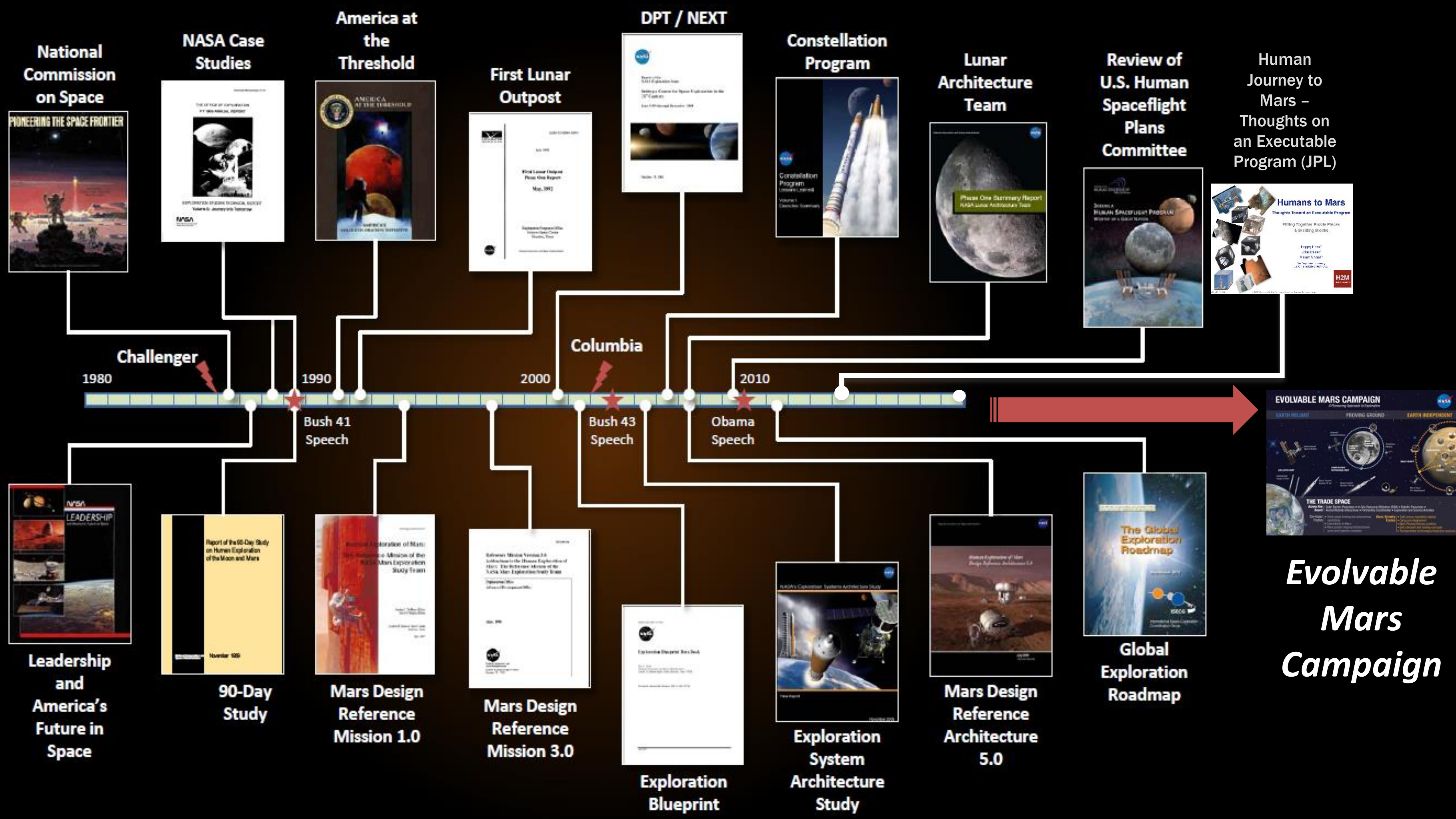
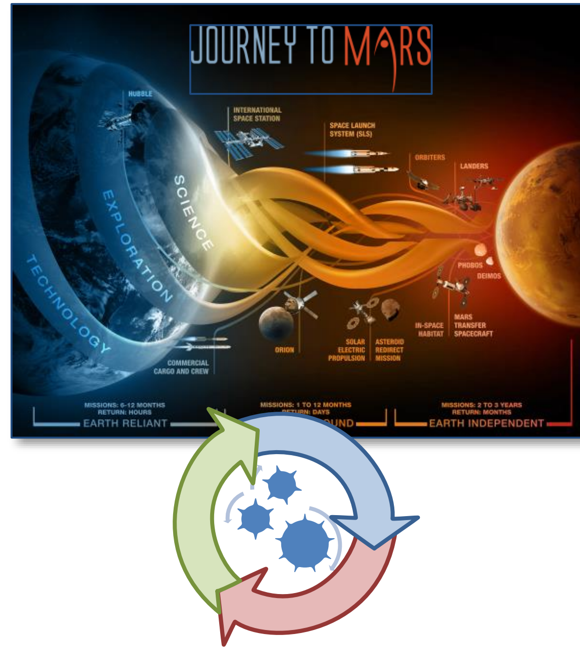
Strategic Principles for Sustainable Exploration

- Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth*;*
- ***Exploration enables science*** **and science enables exploration**, *leveraging robotic expertise for human exploration of the solar system*
- Application of ***high Technology Readiness Level*** (TRL) technologies for near term missions, while focusing sustained investments on ***technologies and capabilities*** to address challenges of future missions;
- ***Near-term mission opportunities*** with a defined cadence of compelling and integrated human and robotic missions providing for an incremental buildup of capabilities for more complex missions over time;
- Opportunities for ***U.S. commercial business*** to further enhance the experience and business base;
- ***Resilient architecture featuring multi-use, evolvable space infrastructure*****,** minimizing unique major developments, with each mission leaving something behind to support subsequent missions; and
- Substantial ***new international and commercial partnerships***, leveraging the current International Space Station partnership while building new cooperative ventures.

A Brief History of Beyond-LEO Spaceflight Architecture Development



Design Reference Missions vs Design Philosophy



Body of Previous Architectures, Design Reference Missions, Emerging Studies and New Discoveries

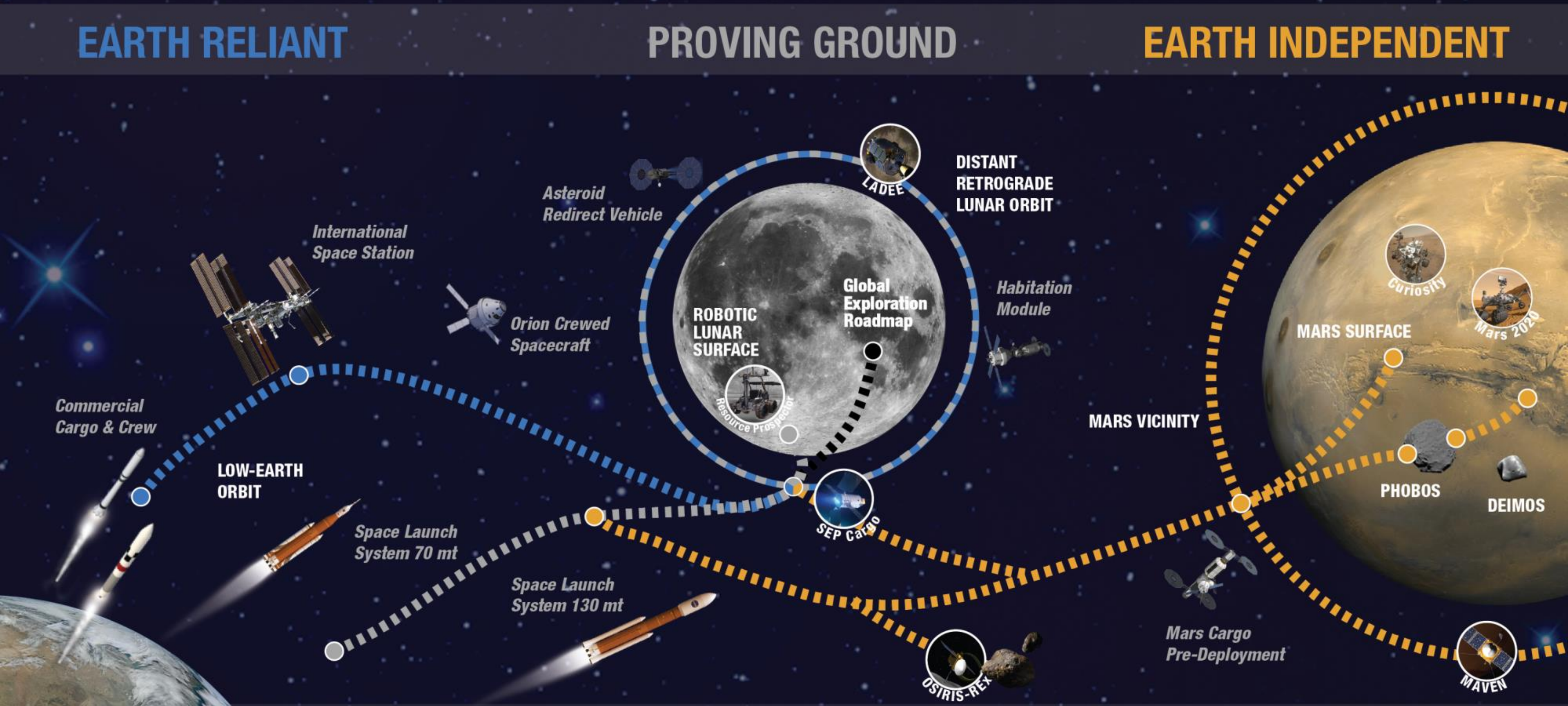
- Internal NASA and other Government
- International Partners
- Commercial and Industrial
- Academic
- Technology developments
- Science discoveries

Evolvable Mars Campaign

- An ongoing series of architectural trade analyses that we are currently executing to define the capabilities and elements needed for a sustainable human presence on Mars
- Builds off of previous studies and ongoing assessments
- Provides clear linkage of current investments (SLS, Orion, etc.) to future capability needs

EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades

- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades

- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

Evolvable Mars Campaign

EMC Goal: Define a pioneering strategy and operational capabilities that can extend and sustain human presence in the solar system including a human journey to explore the Mars system starting in the mid-2030s.

- **Identify a plan that:**
  - Expands human presence into the solar system to advance exploration, science, innovation, benefits to humanity, and international collaboration.
  - Provides different future scenario options for a range of capability needs to be used as guidelines for near term activities and investments
    - In accordance with key strategic principles
    - Takes advantage of capability advancements
    - Leverages new scientific findings
    - Flexible to policy changes
  - Identifies linkages to and leverage current investments in ISS, SLS, Orion, ARM, short-duration habitation, technology development investments, science activities
  - Emphasizes prepositioning and reuse/repurposing of systems when it makes sense
    - Use location(s) in cis-lunar space for aggregation and refurbishment of systems

<u>Internal analysis team members:</u>

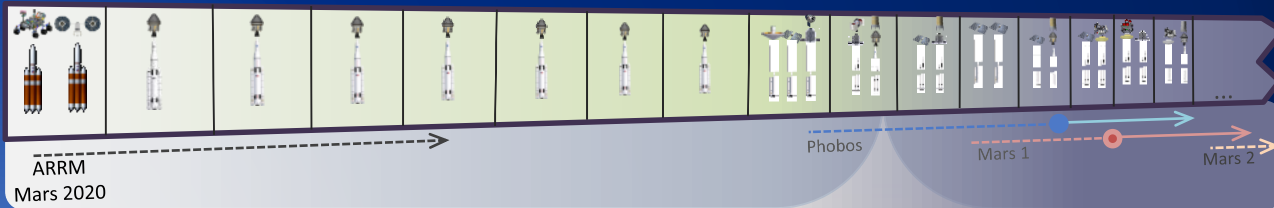
- ARC, GRC, GSFC, HQ, JPL, JSC, KSC, LaRC and MSFC
- HEOMD, SMD, STMD, OCS and OCT

<u>External inputs from:</u>

International partners, industry, academia, SKG analysis groups

EMC Assessment Capability Requires Breadth and Depth

Campaign Analysis, Timelines and Decision Needs



Congress

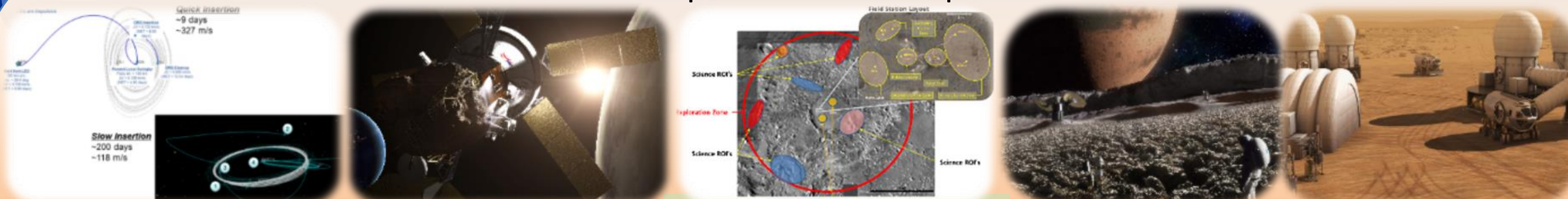
NAC

Int'l Partners

Industry

Public

Mission Operations Development



Trajectory and Orbit Analysis

Proving Ground Ops

Landing Site Selection and Layout

Destination Operations

Element Conceptualization and Design

In-space Transportation Systems

Habitat Sizing

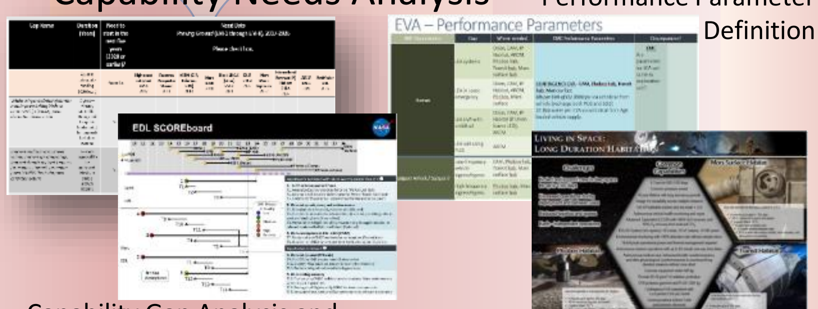
Lander

Mars Ascent Vehicle Design

Destination Systems

Capability Needs Analysis

Performance Parameter Definition



Capability Gap Analysis and Roadmap Development

Pioneering Space Challenges

Strategic Planning

STMD

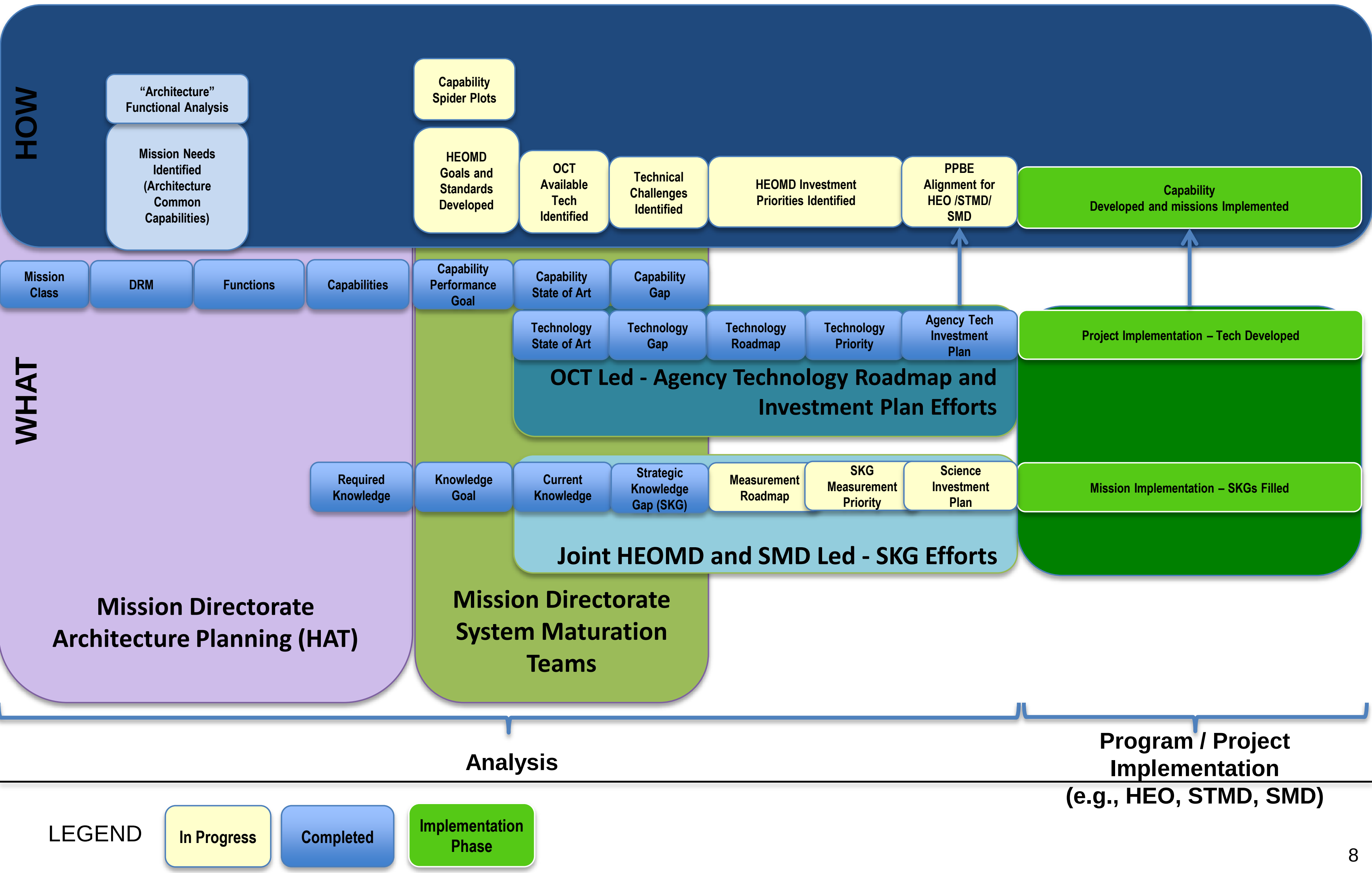
ISS

ESD

AES

NASA Decision Processes, Technology Roadmaps & Strategic Investment Plan

NASA Technology Roadmaps & Investment Plan



EARTH RELIANT

NEAR-TERM OBJECTIVES

DEVELOP AND VALIDATE EXPLORATION CAPABILITIES IN AN IN-SPACE ENVIRONMENT

- Long duration, deep space habitation systems
- Next generation space suit
- Autonomous operations
- Communications with increased delay
- Human and robotic mission operations
- Operations with reduced logistics capability
- Integrated exploration hardware testing

LONG-DURATION HUMAN HEALTH EVALUATION

- Evaluate mitigation techniques for crew health and performance in micro-g space environment
- Acclimation from zero-g to low-g

COMMERCIAL CREW TRANSPORTATION

- Acquire routine U.S. crew transportation to LEO

PROVING GROUND OBJECTIVES

Enabling Human Missions to Mars

TRANSPORTATION

- **Heavy Launch Capability**: beyond low-Earth orbit launch capabilities for crew, co-manifested payloads, large cargo
- **Crew**: transport at least four crew to cislunar space
- **In-Space Propulsion**: send crew and cargo on Mars-class mission durations and distances

WORKING IN SPACE

- **ISRU**: Understand the nature and distribution of volatiles and extraction techniques and decide on their potential use in human exploration architecture.
- **Deep-space operations capabilities**: EVA, Staging, Logistics, Human-robotic integration, Autonomous operations
- **Science**: enable science community objectives

STAYING HEALTHY

- **Deep-Space Habitation**: beyond low-Earth orbit habitation systems sufficient to support at least four crew on Mars-class mission durations and dormancy
- **Crew Health**: Validate crew health, performance and mitigation protocols for Mars-class missions

Demand Areas for Pioneering Space: Steps on the Journey to Mars

	Mission / Demand Areas	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Orbital Proving Ground	Mars Operational
Working in Space and On Mars	In Situ Resource Utilization & Surface Power		Exploratory ISRU Regolith	Exploratory ISRU	Exploratory ISRU & Atmosphere	Exploratory ISRU	Operational ISRU & High Power
	Habitat & Mobility		Initial Short Duration	Long Duration		Resource Site Survey	Long Duration / Range
	Human/Robotic & Autonomous Ops	System Testing	Crew-tended	Earth Supervised	Earth Monitored	Autonomous Rendezvous & Dock	Earth Monitored
	Exploration EVA	System Testing	Limited Duration	Full Duration	Full Duration	Full Duration	Frequent EVA
Staying Healthy	Crew Health	Long Duration	Short Duration	Long Duration	Dust Toxicity	Long Duration	Long Duration
	Environmental Control & Life Support	Long Duration	Short Duration	Long Duration	Long Duration	Long Duration	Long Duration
	Radiation Safety	Increased Understanding	Forecasting	Forecasting Shelter	Forecasting Shelter	Forecasting Shelter	Forecasting & Surface Enhanced
Transportation	Ascent from Planetary Surfaces				Sub-Scale MAV	Sub-Scale MAV	Human Scale MAV
	Entry, Descent & Landing				Sub-Scale/Aero Capture	Sub-Scale/Aero Capture	Human Scale EDL
	In-space Power & Prop		Low power	Low Power	Medium Power	Medium Power	High Power
	Beyond LEO: SLS & Orion		Initial Capability	Initial Capability	Full Capability	Full Capability	Full Capability
	Commercial Cargo & Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity
	Communication & Navigation	RF	RF & Initial Optical	Optical	Deep Space Optical	Deep Space Optical	Deep Space Optical
		EARTH RELIANT	PROVING GROUND				EARTH INDEPENDENT

System Maturation Teams - Integrated capability investment decisions with traceability to human exploration needs

System Maturation Team
Autonomous Mission Operations (AMO)
Communication and Navigation (Comm/Nav)
Crew Health & Protection and Radiation (CHP)
Environmental Control and Life Support Systems and Environmental Monitoring (ECLSS-EM)
Entry, Descent and Landing (EDL)
Extra-vehicle Activity (EVA)
Fire Safety
Human-Robotic Mission Operations
In-Situ Resource Utilization (ISRU)
Power and Energy Storage
Propulsion
Thermal (including cryo)
Discipline Team - Crosscutting
Avionics
Structures, Mechanisms, Materials and Processes (SMMP)

- A key piece to the Pioneering Space strategy is input from System Maturation Teams (SMTs). The SMTs comprise subject matter experts from across the agency who have been involved in maturing systems and advancing technology readiness for NASA.

- The SMTs are defining performance parameters and goals for each of the 14 capabilities, developing maturation plans and roadmaps for the identified performance gaps, specifying the interfaces between the various capabilities, and ensuring that the capabilities mature and integrate to enable future pioneering missions. The subject matter experts that compose each SMT are responsible for understanding their capabilities across all missions and elements within the Evolvable Mars Campaign.

- The SMTs work closely with the Evolvable Mars Campaign to coordinate capability needs and gaps.

Transportation of Crew and Cargo To/From Deep Space

Challenges

Deliver crew and cargo to deep space

Return crew from deep space

Space Launch System

Transport crew and cargo to cis-lunar space

- ✓ Initial launch vehicle that can launch 36 t to TLI
- ✓ Upgraded launch vehicle that can launch 43 t to TLI
- ✓ Option for 5, 8.4, or 10 m diameter shroud
- ✓ 1/year launch rate with surge to 2/year for cis-lunar missions
- ✓ 2/year launch rate with surge to 3/year for Mars missions

Orion

Support crew during trip to/from cis-lunar space

- ✓ 4 crew for 21 days
- ✓ Contingency EVA in a Launch, Entry, and Abort (LEA) suit using umbilical life support
- ✓ Ability to rendezvous and dock with other in-space elements
- ✓ Earth to cis-lunar navigation
- ✓ Earth entry from cis-lunar space: 11 km/s

Commercial Launch

Use commercial launch vehicles to deliver logistics and small cargo to cis-lunar space

- ✓ Small cargo vehicle to deliver up to 11 t to TLI
- ✓ Shroud = 5 m diameter

Living in Space: Habitation

Challenges

Protect and support crew in deep space for up to 60 days (cislunar) or 1100 days (Mars vicinity)

Uncrewed operations during deployment and between uses

Reduced logistics and spares

Earth-independent operations

Common Capabilities

4 Crew for 500-1100 days

Common pressure vessel

15 year lifetime with long dormancy periods

Design for reusability across multiple missions

100 m^3 habitable volume and dry mass < 22 t

Autonomous vehicle health monitoring and repair

Advanced Exploration ECLSS with >85% H_2O recovery and 50% O_2 recovery from reduced CO_2

ECLSS System (w/o spares): <5 t mass, <9 m^2 volume, <4 kW power

Environmental monitoring with >80% detection rate without sample return

14-kW peak operational power and thermal management required

Autonomous mission operations with up to 24 minute one-way time delay

Autonomous medical care, behavioral health countermeasures, and other physiological countermeasures to counteract long duration missions without crew abort

Exercise equipment under 500 kg

Provide 20-40 g/cm^2 of radiation protection

EVA pressure garment and PLSS <200 kg

Contingency EVA operations with 1 x 2-person EVA per month

Communications to/from Earth and between elements

Mars Surface Habitat

Live and operate on the Mars surface in 1/3 g

- ✓ 4 crew for up to approx. 500 days
- ✓ 48 m^3 volume for logistics and spares
- ✓ Logistics Mass: 10.7 t
- ✓ 4 years dormant before use
- ✓ 3-4 years dormant between uses
- ✓ EVA system with surface mobility, dust mitigation, and atmospheric compatibility

Phobos Habitat

Live and operate in microgravity at Phobos

- ✓ 4 crew for up to approx. 500 days
- ✓ 48 m^3 volume for logistics and spares
- ✓ Logistics Mass: 10.7 t
- ✓ EVA system with Phobos mobility and dust mitigation
- ✓ 4-5 years dormant before use
- ✓ 3 years dormant between uses

Transit Habitat

Live and operate in microgravity during trip to/from Mars

- ✓ 4 crew for up to 1,100 days
- ✓ 93 m^3 volume for logistics and spares
- ✓ Logistics Mass: 21 t
- ✓ 4 years dormant before use and between uses

Any initial, short-duration habitation module in the Proving Ground of cislunar space will serve as the initial building block required for Mars-class habitation

IN-SPACE TRANSPORTATION

Challenges

Transport crew and cargo to/from Mars vicinity

Provide access to Mars surface

Provide transportation within the Mars system

Uncrewed operations during deployment and between uses

Mars EDL

Deliver crew and cargo to Mars surface

- ✓ Possible aerocapture at 6.3 km/s if not propulsively delivered to orbit
- ✓ Entry velocity of 3.8 – 4.7 km/s
- ✓ 100 m precision landing with hazard avoidance
- ✓ Supersonic retropropulsion with LOX/CH_4 engine
- ✓ Deployable/Inflatable (16-23 m) entry systems
- ✓ Surface access at +2 km MOLA
- ✓ 20-30 t payload to the surface, 40-60 t arrival at Mars

Common Capabilities

Electric Propulsion

Deliver approx. 40-60 t to Mars orbit

200-kW class solar array system (BOL at 1 AU) using 30% efficient GaAs, triple junction solar cells

300 V array system converted to 800 V for EP and 28 V for spacecraft

ARRM-Derived Hall Thruster:

- ✓ Common Xe storage and feed system with 13.3 kW thruster
- ✓ Isp: 2000 s or 3000 s modes

Chemical Propulsion

Common LOX/CH_4 Pump-Fed Engine:

- ✓ Thrust: 25 klbf
- ✓ Isp: 355-360 s
- ✓ Up to 15 year lifetime
- ✓ 150-500 s burn time
- ✓ 5:1 throttling
- ✓ Near-ZBO storage with 90 K cryocooler

LOX/CH_4 Pressure-Fed RCS:

- ✓ Thrust: 100-1000 lbf; Isp: 320 s

SEP - Hybrid

Combined SEP and hypergolic propulsion system delivers crew and cargo to Mars vicinity

- ✓ 2 x 200-kW class arrays
- ✓ 1,100 days total trip mission time, 300 days at Mars
- ✓ >16 kW thermal rejection
- ✓ Ability to refuel 24 t of Xe on orbit
- ✓ 15 year lifetime, 3 uses, 3 refuelings

Mars Ascent

Return crew and cargo from Mars surface

- ✓ 4 crew and 250 kg payload from $\pm$30 deg latitude, 0 km MOLA to Mars parking orbit
- ✓ 26 t prop (20 t O_2, 6 t CH_4), 35 t total liftoff mass, 8 t Earth launch dry mass
- ✓ Up to 3 days flight duration
- ✓ 5 years dormant before use
- ✓ Use of ISRU-produced oxygen

Mars Taxi

Transport crew and cargo within the Mars system

- ✓ 4 crew for up to 2.5 days
- ✓ 7 t inert mass, 14 t wet mass
- ✓ 8 kW EOL at Mars solar power
- ✓ Reusable and refuelable

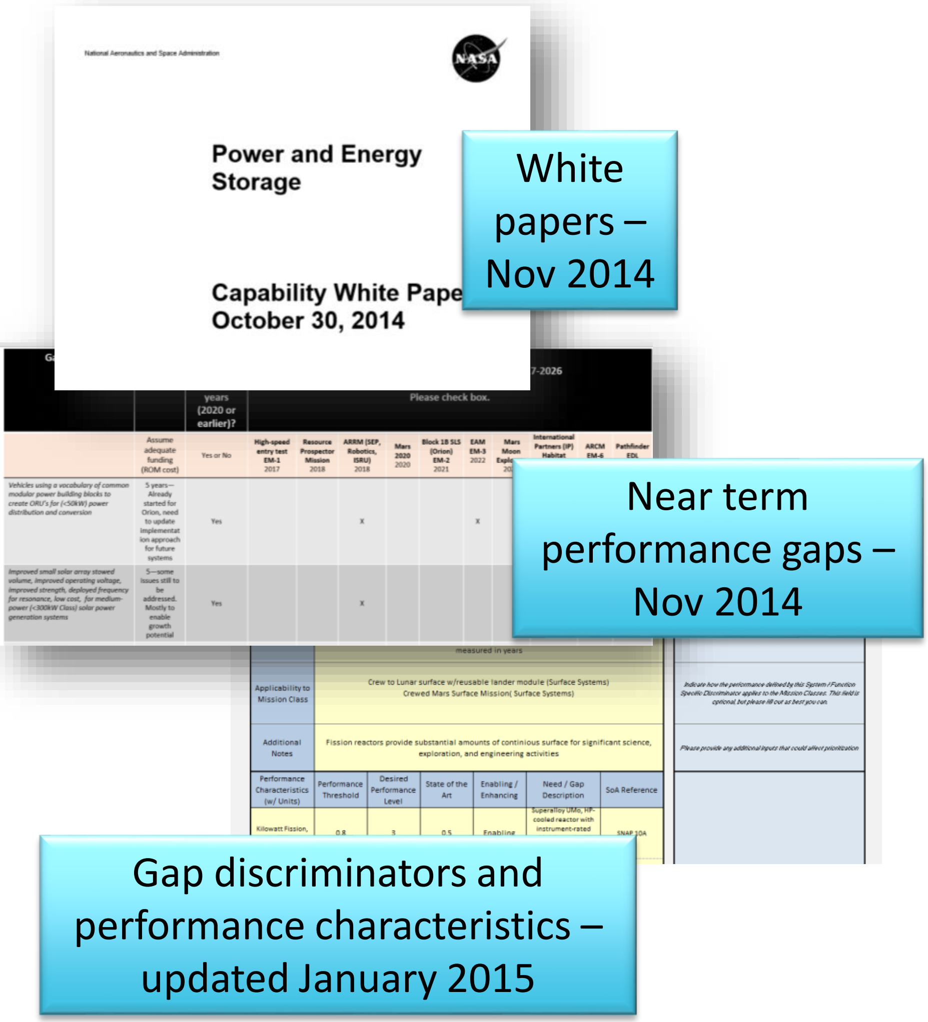
SEP - Chemical

SEP delivers cargo to Mars vicinity, and LOX/CH_4 propulsion delivers crew to/from Mars vicinity

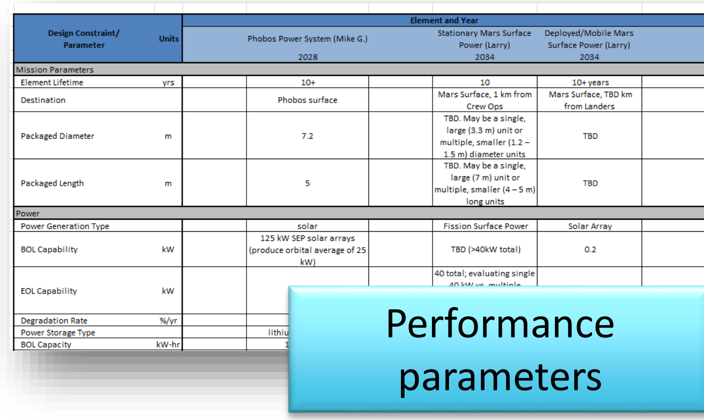
- ✓ 1 x 200-kW class solar array
- ✓ >8 kW thermal rejection
- ✓ Flight times to Mars approx. 1,400 days
- ✓ 4-6 years dormant before use

Data collection and usage

SMT Data Sets



EMC Data Set



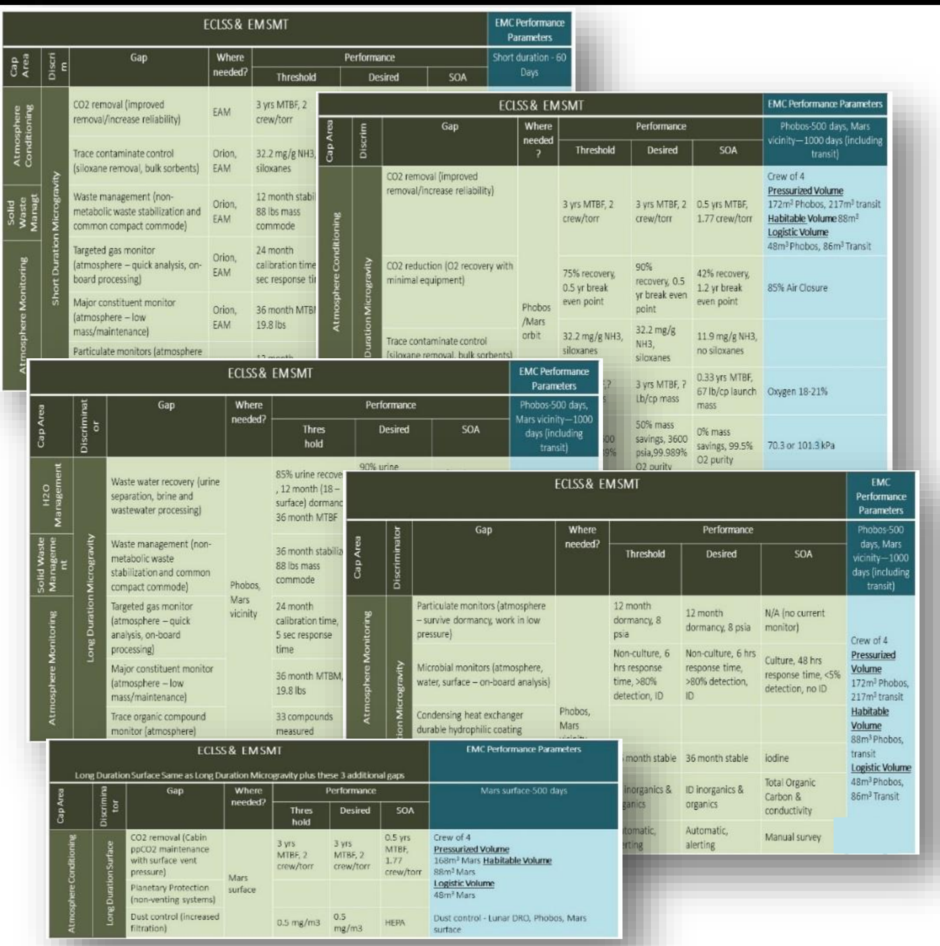
SMT and EMC Performance Metrics Validation

Cap Area	Discrm	EVA SMT: Gap	Where needed?	Performance: Desired	Performance: SOA	EMC Performance Parameters
Exploration PLSS	Surface EVA	PLSS Compatibility with Exploration architecture – Mars atmosphere	Mars surface	Recharge services	EMU	
Exploration EVA Avionics	Avionics	PLSS avionics system	With PLSS/PGS	*Vehicle-born HL comm *A dual-band radio (UHF for mission critical data and 802.11 variant protocol S-Band for high rate) *Separate HD camera connected via 802.11 Wi-Fi or dual-band radio	EMU	**EAM, Phobos hab, Transit hab, Mars surface, and all mobility** EMC specified the same avionics as the SMT
		PGS avionics system				
		Avionics systems for EVA tasks	Any surface EVA		EMU	
Exploration EVA Architecture	Suit Maintenance and Planetary Protection	Long duration EVA Maintenance (>28 days)	Long duration surface	TBD hours MPT, Maintenance Area	EMU	**Phobos hab and Mars surface hab**
		Non-suit dust mitigation	Any geologic work (includes ARCM)	Partner with ECLSS & vehicle teams to mitigate dust, ingress/egress methods, operations (special regions)	Suits leak/vent	Need operational concepts, architecture (specifications of suitport or airlock)
		Planetary protection (forward and backward)	Phobos, Mars			No parameters specified
EVA Integration	Rescue	Integrated rescue operations	All EVA operations	Depends on ops and vehicle architecture		No 'acceptable' levels of dust identified

Example Capability Gap Data Capture: ECLSS

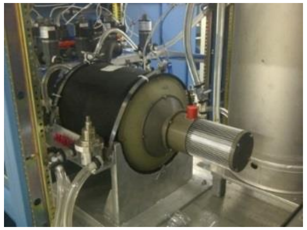
ECLSS & EM SMT							EMC Performance Parameters
Cap Area	Discrim	Gap	Where needed ?	Performance			Phobos-500 days, Mars vicinity—1000 days (including transit)
				Threshold	Desired	SOA	
Atmosphere Conditioning	Long Duration Microgravity	CO2 removal (improved removal/increase reliability)	Phobos /Mars orbit	3 yrs MTBF, 2 crew/torr	3 yrs MTBF, 2 crew/torr	0.5 yrs MTBF, 1.77 crew/torr	Crew of 4 **Pressurized Volume** 172m^3 Phobos, 217m^3 transit **Habitable Volume** 88m^3 **Logistic Volume** 48m^3 Phobos, 86m^3 Transit
		CO2 reduction (O2 recovery with minimal equipment)		75% recovery, 0.5 yr break even point	90% recovery, 0.5 yr break even point	42% recovery, 1.2 yr break even point	85% Air Closure
		Trace contaminate control (siloxane removal, bulk sorbents)		32.2 mg/g NH3, siloxanes	32.2 mg/g NH3, siloxanes	11.9 mg/g NH3, no siloxanes	
Atmosphere Pressure Management		O2 generation system (reduced size and complexity)		3 yrs MTBF,? Lb/cp mass	3 yrs MTBF, ? Lb/cp mass	0.33 yrs MTBF, 67 lb/cp launch mass	Oxygen 18-21%
		High pressure O2 resupply (high frequency EVAs)		50% mass savings, 3600 psia, 99.989% O2 purity	50% mass savings, 3600 psia,99.989% O2 purity	0% mass savings, 99.5% O2 purity	70.3 or 101.3 kPa

Environmental Control and Life Support System – Environment Monitoring (ECLSS-EM) SMT

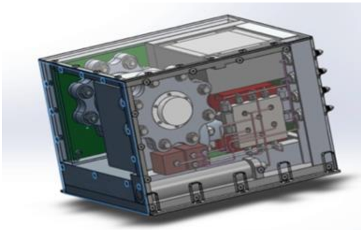


AES – FY16 Activities

- ✓ **Life Support Systems:** Developing improved sorbents for CO_2 removal, High Pressure Oxygen Generation system for replenishing space suits, Cascade Distillation System for waste water processing, and Spacecraft Atmosphere Monitor for detecting trace gas contaminants in ISS air.
- ✓ **Next Space Technology Exploration Partnerships (NextSTEP):** Developing advanced CO_2 removal technologies, modular ECLSS, and hybrid biological and chemical life support systems.
- ✓ Feeds forward to short and long duration habitats used for transit and surface destinations.



Cascade Distillation System



Spacecraft Atmosphere Monitor

Life Support Systems: Completed Systems Requirements Review for Spacecraft Atmosphere Monitor. ISS demo planned in 2018.

Commonality: Advantages and Disadvantages

Advantages

- Reduced cost (one vs. multiple DDT&E)
- Improved safety (common operations)
- Reduced logistics (same spares for different habitats)
- Simplified infrastructure integration (one interface vs. multiple)
- Simplified training (one system vs. multiple)

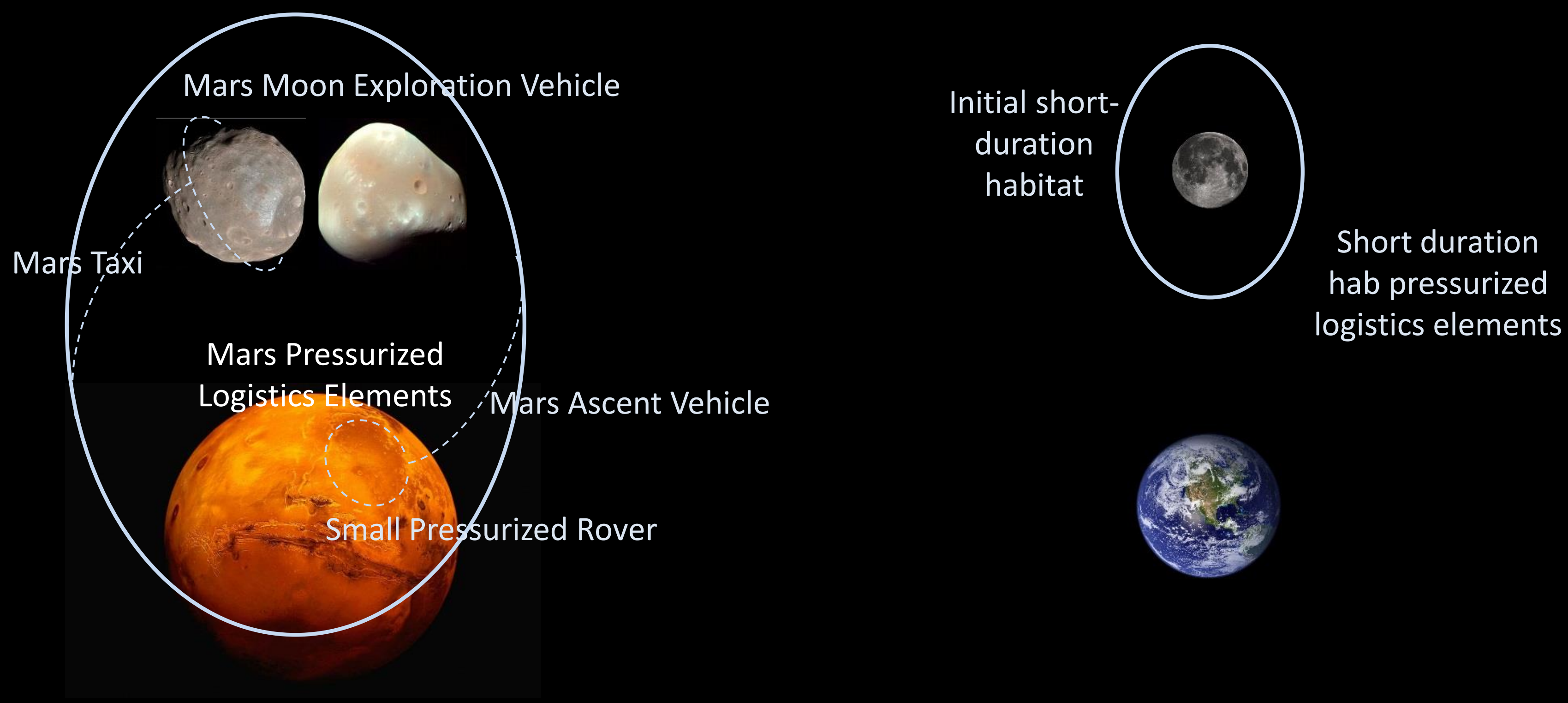
Disadvantages

- Sub-optimized (each application usually gives up unique attributes)
- May preclude inclusion of latest technology

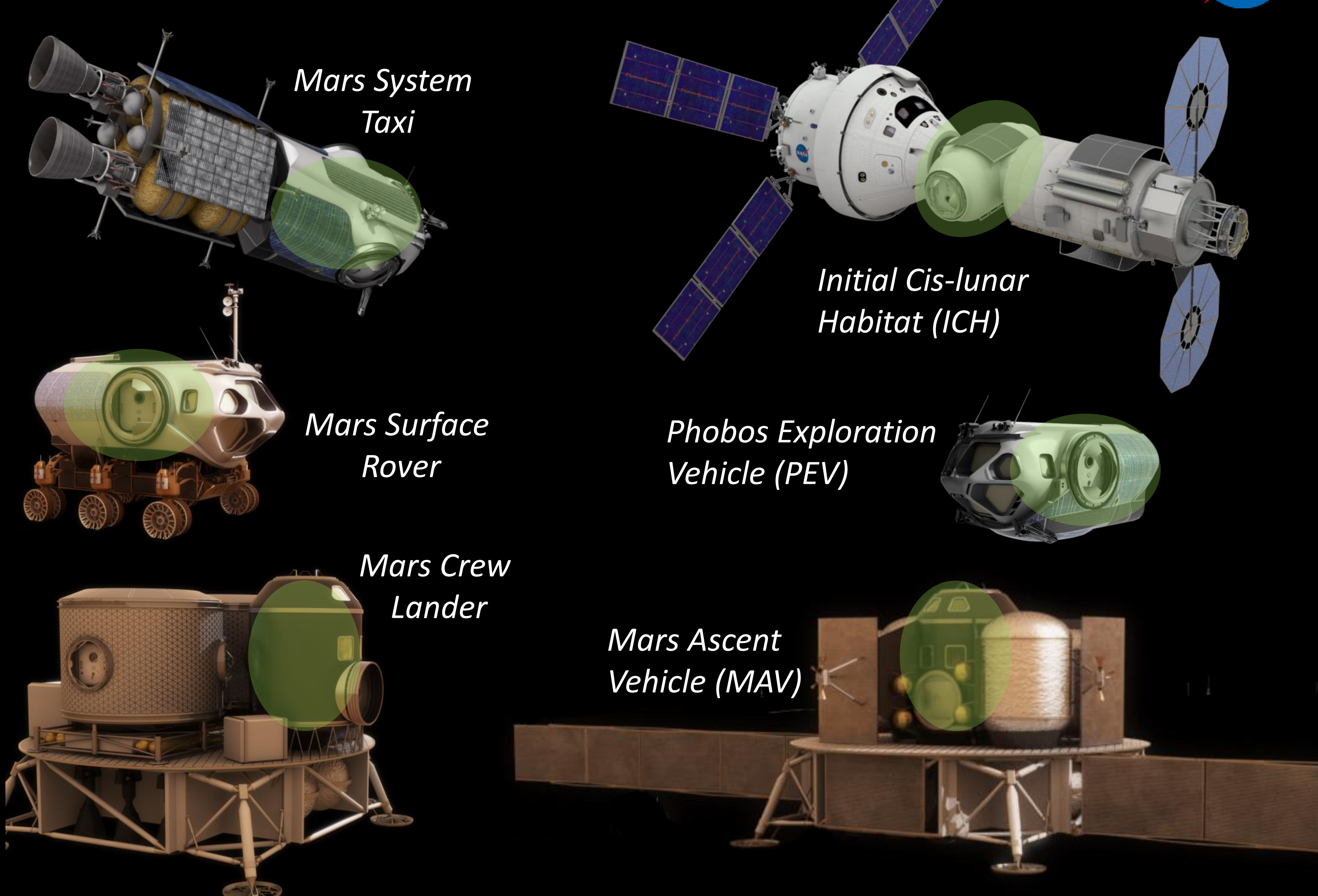
Space Station Common Module

Inter-modal Cargo Container

EMC Small Habitat Commonality Scope

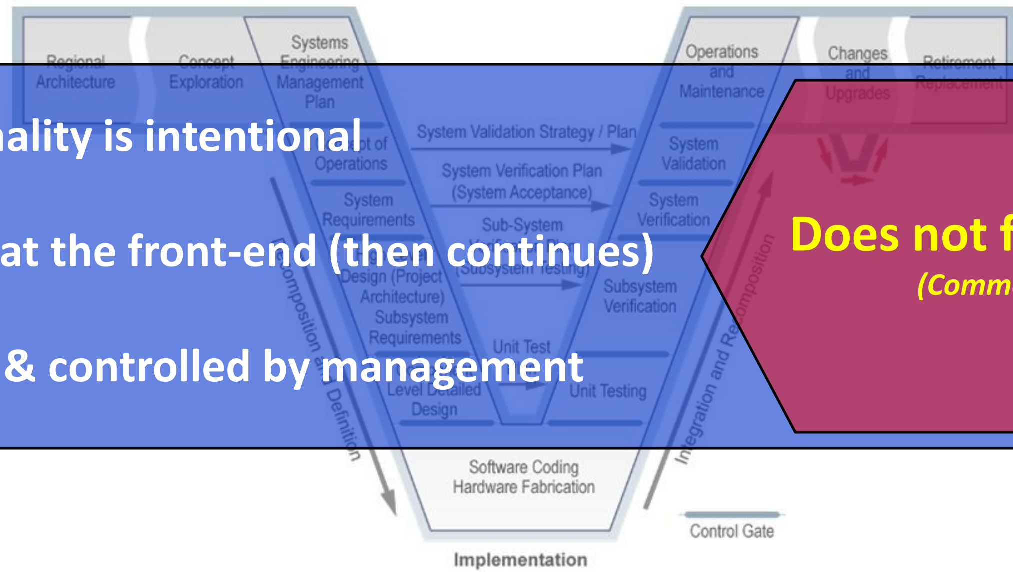


EMC Small Habitat Commonality Scope



Commonality: Lead From the Start and Never Stop

Program Development



Commonality is intentional

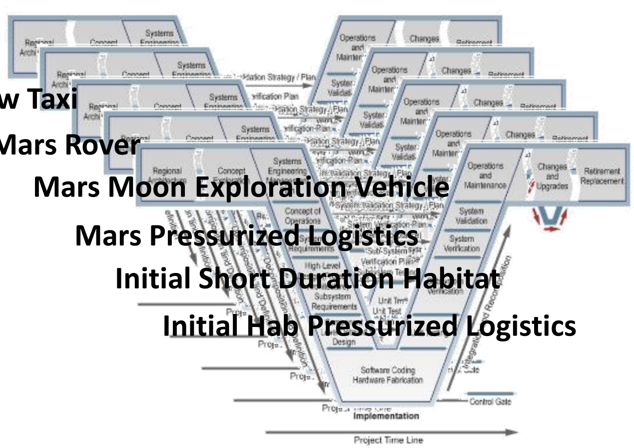
Must be at the front-end (then continues)

Initiated & controlled by management

Does not flow this way

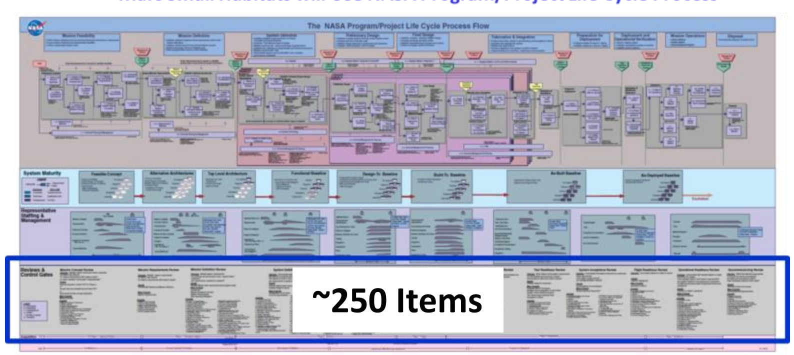
(Commonality lost)

Unique DDT&E



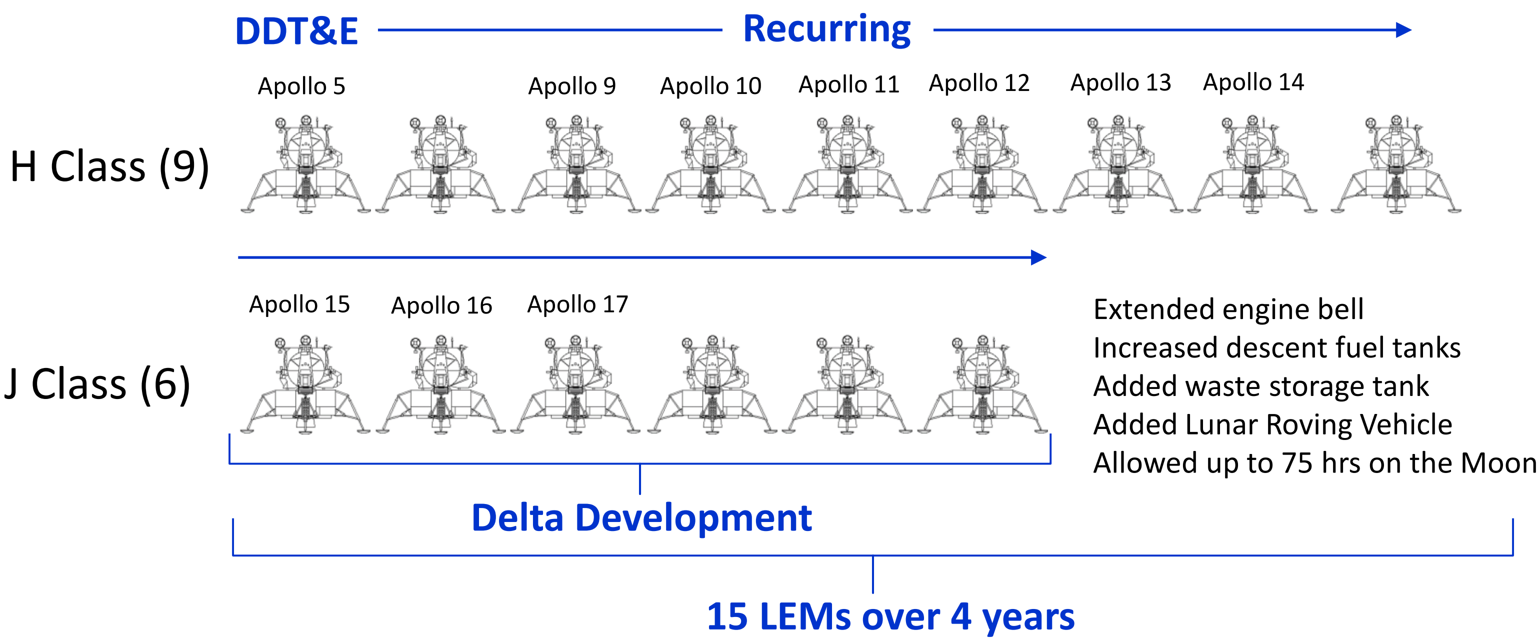
NASA Program DDT&E

Mars Small Habitats will Use NASA Program/Project Life Cycle Process



Example of Core Commonality

Apollo Lunar Excursion Module

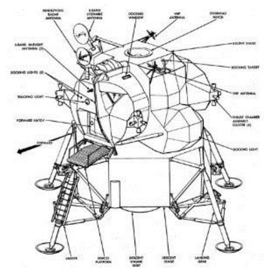


Analogous Small Hab DDT&E vs. Recurring

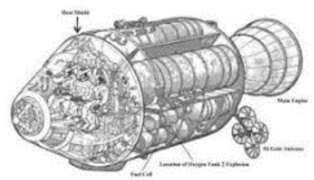
Lunar Excursion Module and Command Service Module

- **Small Habitats**
- **Mission Beyond Low-Earth Orbit**
- **Gravity and Weightless Operations**
- **Flight Hardware**
- **Good Documentation**

Lunar Excursion Module



Command Service Module



Green=Apollo by the Numbers, A statistical reference for the manned phase of Project Apollo, by Richard W. Orloff

				CSM peak	LEM peak				
	In $000 real year dollars ->			56%	57%				
	1963	1964	1965	1966	1967	1968	1969	1970	
Lunar Module	$ 123,100	$ 135,000	$ 242,600	$ 310,800	**$ 472,500**	$ 399,600	$ 326,000	$ 231,433	
Command and Service Module	$ 345,000	$ 545,874	$ 577,834	**$ 615,000**	$ 560,400	$ 455,300	$ 346,000	$ 282,821	
Inflation Adjustment									
NASA Inflation Factor to 2015	11.159	10.678	10.327	9.743	9.287	8.812	8.336	7.798	
	In 2015 dollars $B ->								**2015 SUM $B**
Lunar Module	$ 1.374	$ 1.442	$ 2.505	$ 3.028	$ 4.388	$ 3.521	$ 2.718	$ 1.805	**$ 20.780**
Command and Service Module	$ 3.850	$ 5.829	$ 5.967	$ 5.992	$ 5.204	$ 4.012	$ 2.884	$ 2.205	**$ 35.944**
Estimation	**Low est.**	**High est.**							
Total manufactured LEMS	9	11.5		(Lo=Operational Units, Apollo 9 thru 17; Hi adds 2.5 units in varying stages of manufacture)					
Total manufactured CSMs	11	13.5		(Lo=Operational Units, Apollo 7 thru 17; Hi adds 2.5 units in varying stages of manufacture)					
								Last two years	
Lunar Module, % of Total that was for Manufacture of Units	22%	43%						22%	of total
CSM Module, % of Total that was for Manufacture of Units	14%	44%						14%	of total
	2015 $B Hi/Lo	**2015 $B Lo/Hi**	**2015 $B Avg.**						
LEM, DDTE	$ 16.21	$ 11.91	**$ 14.06**						
LEM per Unit	$ 0.398	$ 0.99	**$ 0.69**						
CSM DDTE	$ 30.91	$ 20.09	**$ 25.50**						
CSM per Unit	$ 0.37	$ 1.44	**$ 0.91**						

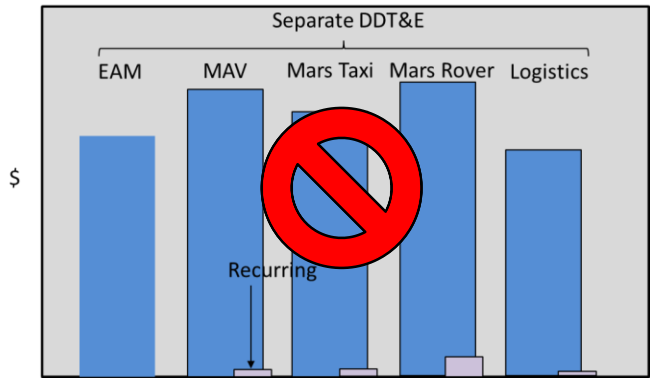
Landers $14B then $700M ea.

Lunar Spacecraft- $26B then $900M ea.

Objective: Maximize Small Habitat Commonality

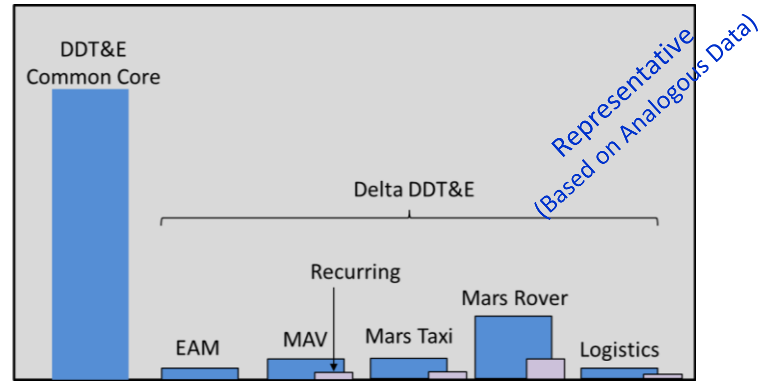
Without Commonality

(Separate Parallel Development)



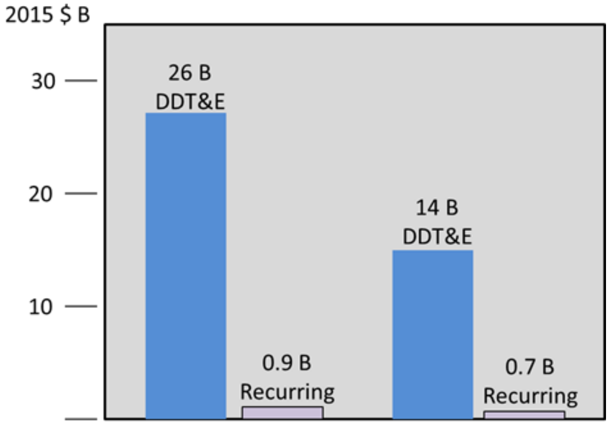
Commonality Objective

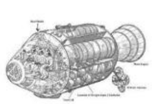
(Single Major Development with Small Delta Developments)



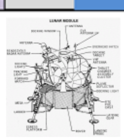
Benefits of Common Core

(Analogous Program DDT&E vs. Recurring)



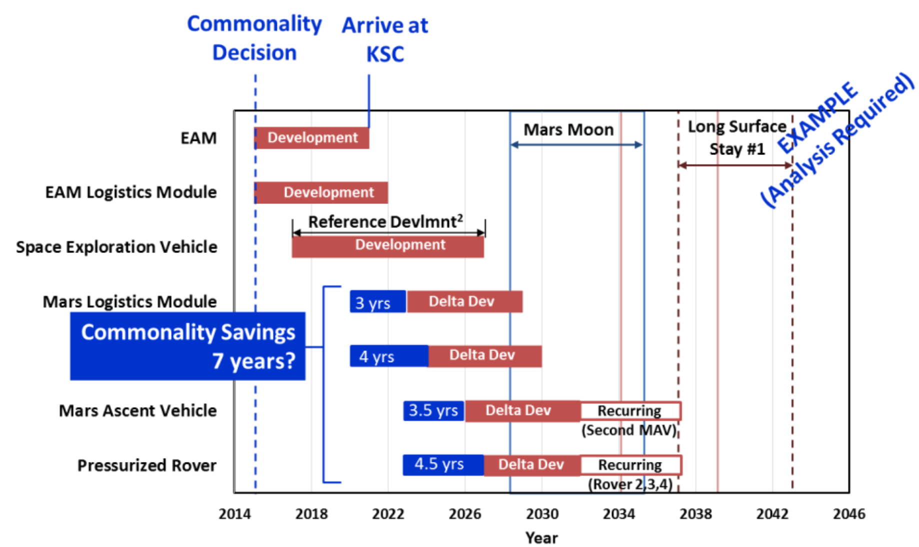


CSM

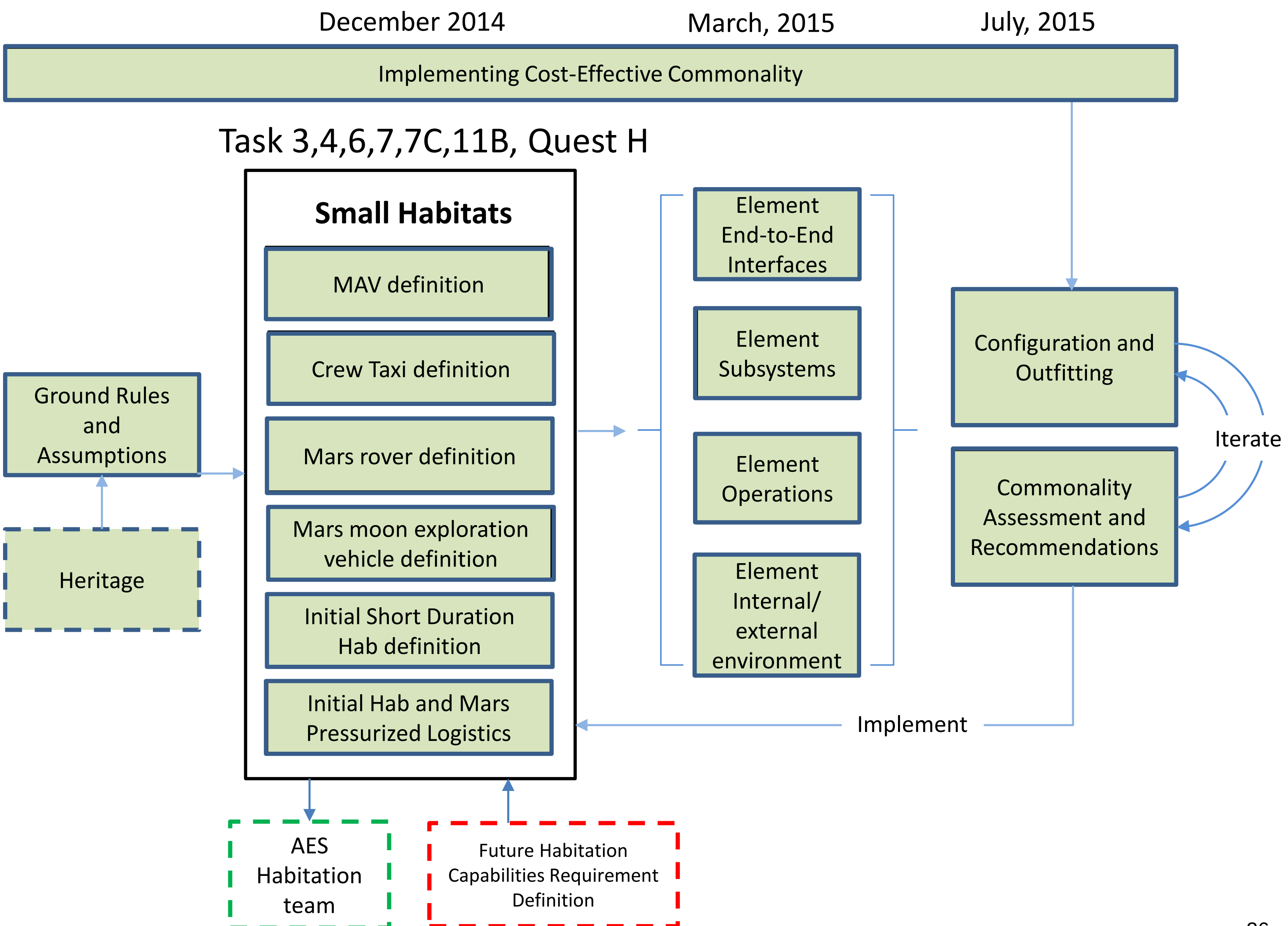


LEM

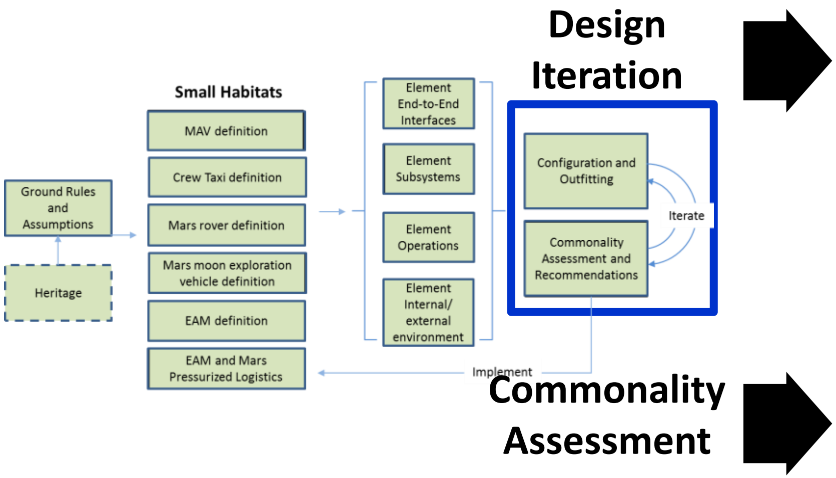
Reduced Program Schedule

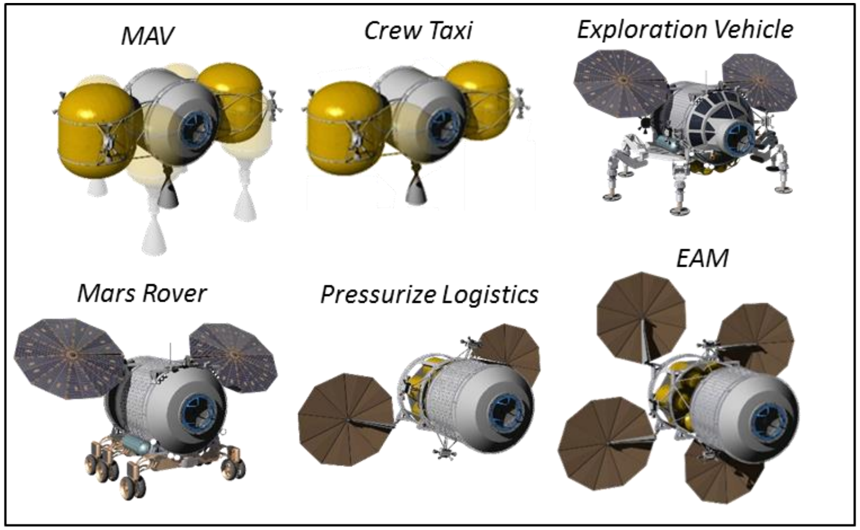


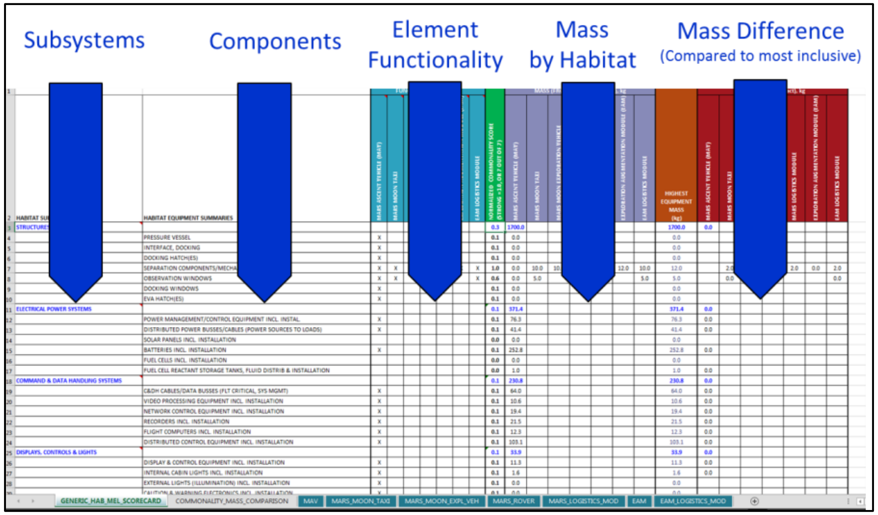
How can we maximize commonality across Mars ascent, Mars vicinity taxi, exploration vehicle and initial deep space habitation component?



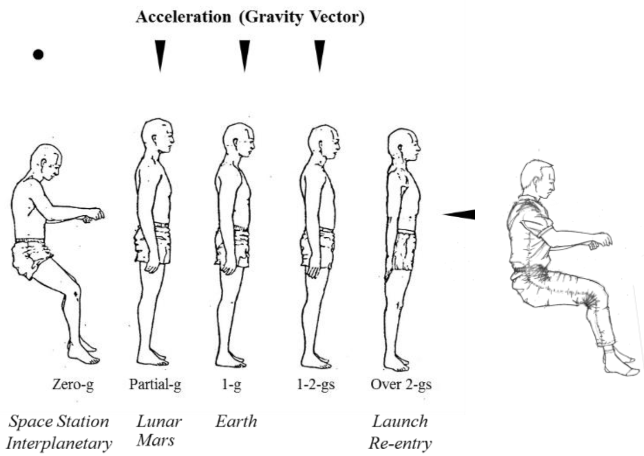
Validate/Assessment Cycle

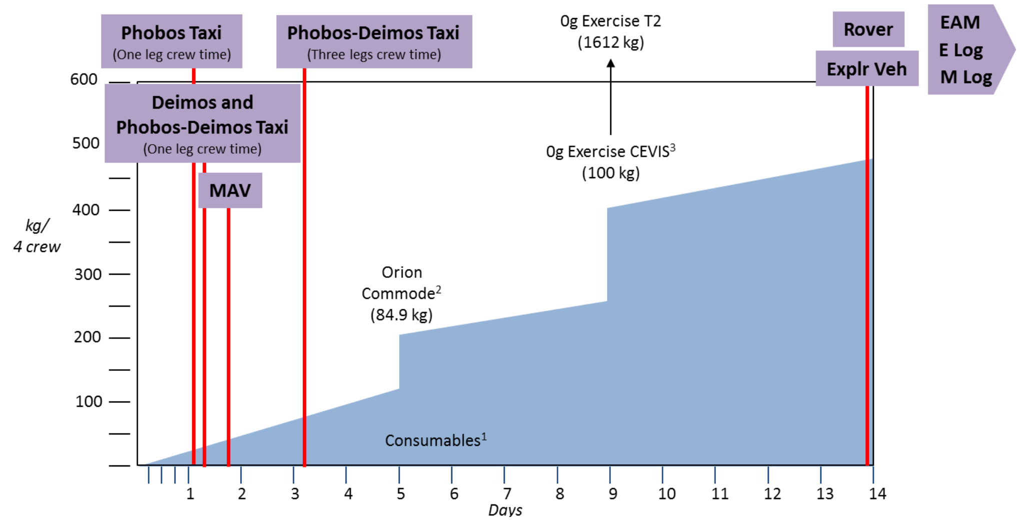


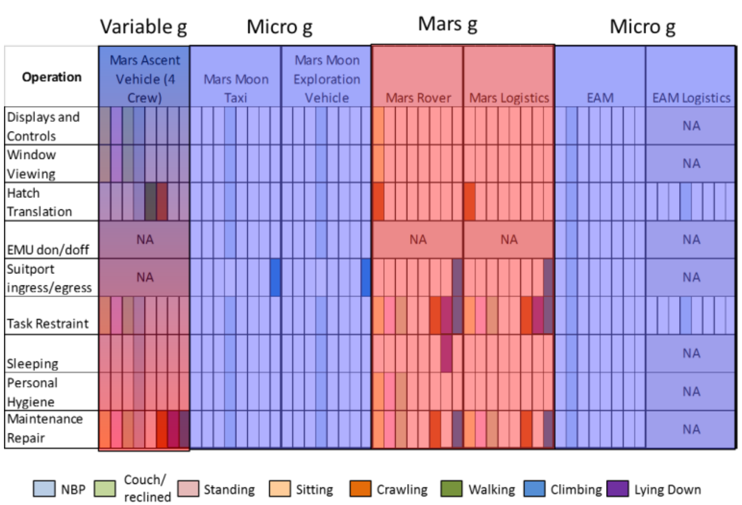




Crew Operating Postures







Transit Phase	Mars Ascent Vehicle	Mars Moon Taxi	Mars Moon Exploration Vehicle	Mars Logistics	Mars Rover	EAM	Logistics
Launch	NA	If M[illegible]rs Mo[illegible]n [illegible]axi travels with Transit H[illegible] to [illegible]RO T[illegible]sfe[illegible] EV[illegible] Su[illegible] a[illegible]d 4 M[illegible]ACE[illegible]	2 su[illegible]por[illegible]s, umbilicals, 2 EVA suits and sup[illegible]rt s[illegible]. per [illegible]over	~12 EVA [illegible] [illegible]ogi[illegible]tics and [illegible]spares, EVA Consumables	If crew lands in rovers: 2 suitports, [illegible]mb[illegible]ic[illegible]ls, E[illegible]A [illegible]uit [illegible]ar[illegible]d s[illegible]pp[illegible]rt [illegible]ys. per rover, [illegible]MA[illegible]ES [illegible]its [illegible]re t[illegible]ans[illegible]err[illegible]d fo MAV (2 on ea. Rover)	Airlo[illegible]port- Airlo[illegible]bilicals, suppo[illegible]	EVA c[illegible]nables, logis[illegible]pares
DRO staging						2-4 [illegible] S[illegible] and supp[illegible]rt sys	EVA c[illegible]nables, logis[illegible]pares
Transit/outbound						NA	NA
Mars Orbit		Transfer 4 EVA suits [illegible] w[illegible]l ha[illegible] to [illegible]e on suitports)				NA	NA
EDL		NA				NA	NA
Surface		NA			[illegible]EV[illegible]su[illegible] [illegible]er r[illegible]ver [illegible]nd [illegible]upp[illegible]rt s[illegible]s	NA	NA
Ascent	Transfer 4 M[illegible]AC[illegible]S*, u[illegible]bi[illegible]cal[illegible], and support sys.	NA	NA	NA	NA	NA	NA
Transit/return*	NA	NA	NA	NA	NA	NA	EVA c[illegible]ables, logi[illegible]pares
DRO*	NA	NA	NA	NA	NA	EVA c[illegible]ables, logis[illegible]ares	EVA c[illegible]ables, logi[illegible]pares
Earth Entry*	NA	NA	NA	NA	NA	NA	NA

2 EVA suits are always on Mars Transfer Vehicle
*MACES for Transit/return, DRO, and Earth Entry on Mars Transfer Vehicle

MACES 0g EVA Mars EVA Mars Spares Logistics[19]

NextSTEP BAA Overview

- **Solicited three critical areas for technology maturation:**
  - Advanced Propulsion Systems
  - Habitation Systems (Including Life Support)
  - Small Satellite Missions (EM-1 secondary payloads)

- **Facilitates development of deep space human exploration capabilities in the cis-lunar proving ground and beyond**
- **Continues successful public-private partnership model and spurs commercial endeavors in space**
- **Selected 12 proposals and will proceed to enter into *Fixed Price Contracts* with technical/payment milestones with private-sector partners**
  - Emphasis for eligibility and execution placed on contribution of private corporate resources to the private-public partnership to achieve goals and objectives
  - Selected partners with the technical capability to mature key technologies and demonstrate commitment toward potential commercial application

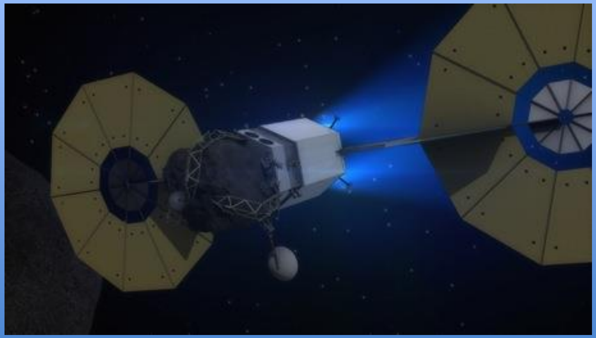
Proving Ground Top Level Goals

Note- concepts shown are notional

Initial Phase of Proving Ground

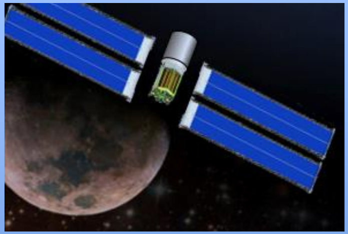
End of Proving Ground

In-Space Transportation Evolution



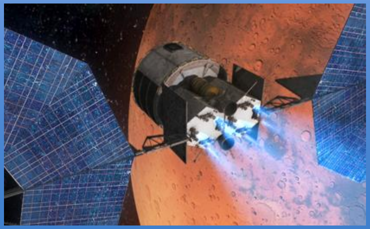
ARM SEP Development

OR



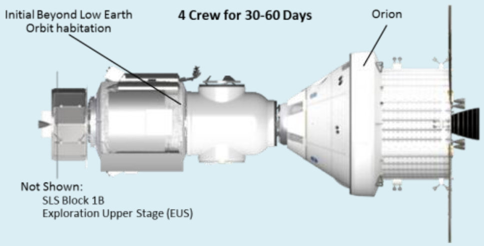
Split SEP / Chemical

Mars-Class Mission SEP Validation



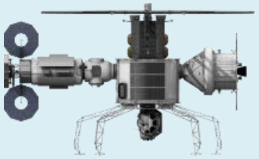
Hybrid SEP / Chemical

Long Duration Habitation Evolution



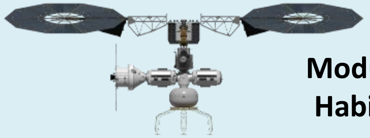
Initial Beyond Low Earth Orbit Habitation Development

OR



Monolithic Habitat

Mars-Class Mission Habitation Validation



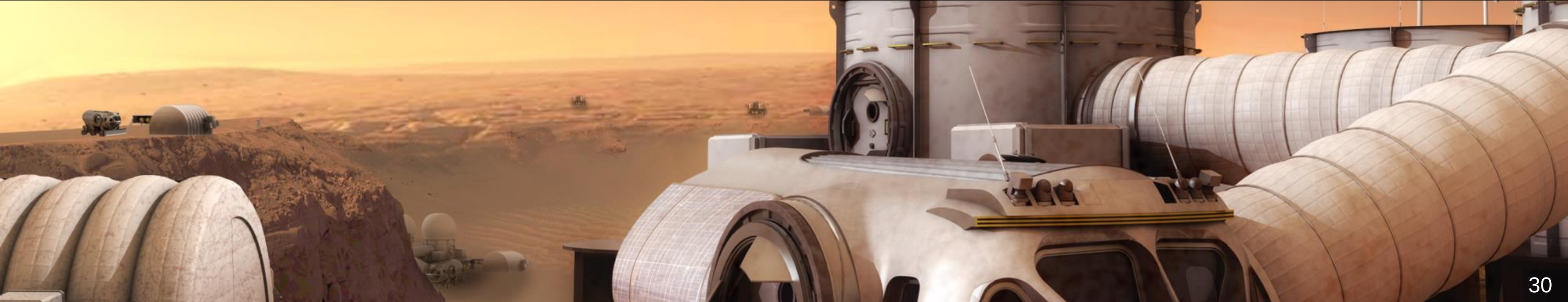
Modular Habitat

EMC FY16 Plans
– Interim Results / Mar 2016; Final Results / June 2016

- **Transportation**
  - Refinement of Hybrid and SEP/Chem transportation architectures for closure (including proving ground Flight Test Objectives (FTO))
  - Sensitivities of additional capability investments for transportation architectures
  - Assessments of alternate transportation scenarios as needed
- **Habitation**
  - AES Mars Habitat driven design (definition of advanced habitation roadmaps, we know what we need to get to, but don't know how to get there)
  - Assessments of alternate habitation system designs (Future Capability Team Modular and BAA commercial) on EMC architecture
- **Pathfinders**
  - EDL path finder strategy and assessment
  - Provide Mars Moon SKGs for Mars Orbiter/moon pre-cursor
- **Tele-operations**
  - Define low latency tele-operations for Mars Moons and for Mars surface via Mars moons. Link back to FTOs in cis-lunar and ISS
- **Mars Surface Pioneering**
  - Develop Surface strategy, capabilities and layout beyond initial boots on Mars that leads to Earth Independence
- **ISRU**
  - An ISRU strategy that begins on ISS, expands to cislunar space, proceeding to the Mars vicinity and ultimately the Mars surface will be developed.
  - FTOs and system concepts for each step will be developed
- **Partnerships and External Engagement**
  - FY16 EMC reports
  - Engagement Workshop(s)
  - OCE Engagement / CLT
  - OCT Engagement / Resiliency Studies
  - ISECG Engagement
  - Media Products

Summary

- The Journey to Mars requires a resilient architecture that can embrace new technologies, new international / commercial partners, and identify agency investment choices to be made in the near, mid and long term.
- The Evolvable Mars Campaign:
  - Informs the agency choices by providing technical information from a cross agency, end-to-end integrated analysis
  - Needs to continue to develop linkages to the agency decision making and capability investment processes
- Regardless of which path is ultimately selected, there are a set of common capabilities required to be developed by NASA and its partners over the next 10 years



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